Sediment Acoustics

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LONG-TERM GOAL

The long-term goal of my work in sediment acoustics is to develop a practical as well as physically meaningful model to describe geoacoustic wave propagation in marine sediments on the basis of a set of primitive physical variables.

OBJECTIVES

The principal scientific objective of my work has been to develop a mathematical model that is able to predict wave velocity and attenuation in the sediments found near the seafloor. Specifically, the model has been designed to accept as input parameters certain fundamental primitive variables, such as grain size, porosity, grain density and gas content that are directly related to the geological processes producing the wide range of sediments that are encountered in the world's oceans. A number of auxiliary technological objectives have also arisen in the course of our work related to remote sensing and in-situ measurement of sediment geoacoustic properties. One of these objectives has been to develop a set of tools that allow the measurement of velocity and attenuation as well as certain related geotechnical variables such as shear strength in the sediment column. These measurements provide the “ground truth” for assessing the validity and usefulness of the basic geoacoustic model.

APPROACH

My approach has been to develop a theoretical geoacoustic model based on the classical Biot theory for porous, fluid-filled media. The model reflects the influence of variables such as porosity and overburden pressure and includes several kinds of intrinsic attenuation that are important in different kinds of ocean sediment. We have performed extensive field and laboratory experiments aimed at determining appropriate input parameters as well as checking the validity of the model predictions. Much of our earlier work is described in the monograph "Sediment Acoustics" (Stoll, 1989). More recent progress, especially the results of extensive field work, has been described in a series of technical papers and is being incorporated into several new chapters in a second edition of the monograph to be published in the near future. Over the past several years we have participated in a number of field experiments in cooperation with other investigators such as T. Akal at SACLANT Undersea Research Center in LaSpezia, Italy and M. Richardson at the Naval Research Laboratory, Stennis Space Center. During this work several new testing techniques were developed to measure in-situ properties of the sediments immediately beneath the seafloor including shear wave velocity and attenuation for both vertically and horizontally polarized wave motion, and undrained shear strength based on quasistatic cone penetration tests. In addition, sediment cores taken at many sites were analyzed to obtain porosity, grain size distribution and other fundamental properties, the objective being to establish the ground truth at each

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test location and develop correlations between such quantities as in-situ shear wave velocity, undrained shear strength and porosity.

In addition to the field work mentioned above, a new series of laboratory experiments were begun with the purpose of studying the dispersion that occurs during p-wave propagation in granular sediments as one moves from the “low frequency” regime to the “high frequency range” that is currently of considerable interest. The purpose of this work is to help in the evaluation of some of the new propagation models are being proposed to explain the penetration of acoustic energy into the seafloor at low grazing angles that has been observed in recent experiments. Some of these new models that are based largely on high frequency data, and in some cases idealized scattering models, do not properly account for the dispersion that would normally be expected in going from low to high frequencies and therefore may be questionable for applications in the general case.

WORK COMPLETED

During the past year our research team, which includes R. Stoll and I. Bitte from Lamont-Doherty Observatory and R. Flood from the Marine Research Lab, SUNY, Stonybrook, participated in a major field experiment on board the NAVOCEANO Ship Pathfinder in the shallow water near Cape Trafalgar off the southern tip of Spain. This work was part of NATO exercise ‘Rapid Response 98' and involved the use of both expendable (XBP) and retrievable seafloor penetrometers to rapidly evaluate seafloor geotechnical and geoacoustic properties of interest in mine-countermeasures activities. During this exercise and a similar one in 1997 in the Bay of Saros, Turkey, a new beach and surf-zone penetrometer was deployed to study beach trafficability and other properties in a potential amphibious landing area.

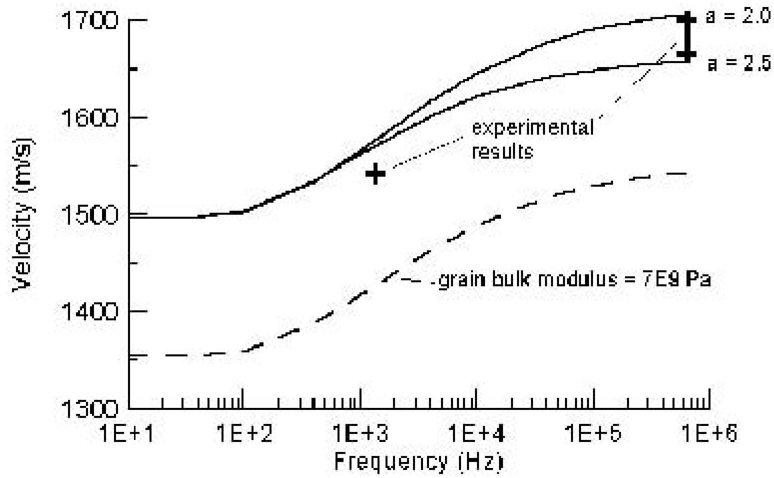
During FY 98, laboratory experiments designed to measure p-wave velocity in granular sediment were carried out using a new experimental technique wherein the vertical, effective stress in a specimen was reduced to a very low value by the introduction of vertical, steady state fluid flow before wave-velocity measurements were made. Acoustic measurements were made at several frequencies in the high frequency range (> 50 kHz) and one preliminary experiment at lower frequency (1.3 kHz) was performed. The experiments were then modeled using the Biot theory in order to evaluate the effect of changes in certain parameters such as grain bulk modulus and permeability (Stoll, 1998a). Fig 1 shows some results from these experiments. The solid curves show the predictions of the theory using traditional values for the various moduli whereas the dashed curve shows the prediction when an anomalously low value is used for the modulus of the grains.

RESULTS

Our field work in FY 98 and the previous several years has demonstrated the feasibility of classifying the seabed sediments with respect to certain geoacoustic and geotechnical properties by deploying expendable probes which impact the bottom and measure the penetration resistance of the sediment. The penetration resistance, which is controlled by the undrained shear strength of the sediment, has been found to correlate well with sediment shear wave velocity as well as sediment porosity. With this information it is possible to make a reasonable estimate of the full geoacoustic response of the sediment with the aid of the mathematical model that has been developed using the Biot theory.

The preliminary results of our new laboratory experimental work suggest that traditional values of certain parameters such as grain bulk modulus and frame bulk modulus, that have been used by investigators for many years, are reasonable and that some recent studies, wherein anomalously high or

Fig. 1 Experimental results and predictions using Biot theory.



low values have been arbitrarily chosen for these parameters to match test results, lead to a physically unrealistic model. A partial discussion of this problem is given in Stoll (1998b).

IMPACT/APPLICATION

While our primary interest has been to model geoacoustic properties of the sediment, a number of tools developed for our field work have direct applications to other areas of interest to the Navy such as mine counter-measures. As an example, the penetration resistance measured by several different types of probe we have developed is directly related to the bearing capacity of the sediment which is of prime importance in studies of mine burial in the seafloor. These probes have been used to map critical areas in two recent NATO exercises aimed at 'Rapid Environmental Assessment'.

Another application of our work this past year is the adaptation of the beach penetrometer for use in the surf zone for studies of the effect of entrapped air on the attenuation of strong surface waves in the surf zone. We have built a new version of this penetrometer for work being performed by Dale Bibee of NRL Stennis.

TRANSITIONS

We are currently preparing and XBP (expendable bottom penetrometer) evaluation package for the Naval Oceanographic Office composed of software, an electronics interface board and a users manual for use on board NAVO ships.

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PUBLICATIONS

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